

The University of Chicago

EXPERIMENTS IN GROUP BEHAVIOR OF FISHES

A PART OF A DISSERTATION SUBMITTED
TO THE FACULTY OF THE DIVISION OF THE
BIOLOGICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF ZOÖLOGY
1932

By
JOEL CARL WELTY

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EXPERIMENTS IN GROUP BEHAVIOR OF FISHES

(Eleven figures)

JOEL CARL WELTY

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BACKGROUND LITERATURE¹

FISHES were not credited with an ability to learn through experience until Möbius (1873^b) performed his much-quoted experiment. Subsequent and increasingly critical experiments have shown that fishes are capable of considerable learning. In verifying Möbius' work, Triplett (1901) placed two perch in one end of an aquarium and separated them from minnows in the other end by a glass partition. After repeatedly dashing against the partition to catch the minnows the perch became so thoroughly conditioned against them that they would not rush toward the minnows even though the partition were removed and the minnows swam about them. However, if worms were dropped on the other side of the partition the perch again dashed violently against it in their attempts to eat. This showed that they had learned to avoid the minnows and not the partition, and that they had not merely become fatigued. This conditioned-response technique has been fruitfully used in most of the subsequent experiments in the behavior of fishes.

Thorndike (1899), Goldsmith (1905, 1914) and Churchill (1916) trained fishes to run mazes and showed that both sight and "motor memory" played a part in the conditioning process. Experiments on color vision in fishes proved that they can discriminate a wide range of colors: Zolonitsky (1901), Washburn and Bentley (1906), Reighard (1908), von Frisch (1912), Goldsmith (1914), Schaller (1926), and Bull (1928). That fishes can discriminate wave lengths and not merely intensities of light was definitely shown by White's (1919, 1927) work with mudminnows and sticklebacks.

¹ Not only for suggesting this project but also for his helpful interest in it throughout, I wish to express my deep gratitude to Dr. W. C. Allee. In part this work was aided through a grant to the University of Chicago from the Rockefeller Foundation.

Fishes are easily and quickly trained to form motor responses to sound vibrations: McDonald (1922), Westerfield (1922), von Frisch (1923*b*), and Bull (1928). Stetter (1929) found fishes had an auditory range of over five octaves and that their auditory acuity compared favorably with man's.

Further discriminatory capacities of fishes have been discovered through recent work. Bull found that the blenny could form conditioned responses to slight changes in temperature or salinity of the surrounding water. Strick (1924) discovered that blinded *Phoxinus* could discriminate between grape sugar, acetic acid, and quinine even after extirpation of the forebrain. Trudel (1929) trained minnows to recognize various sweet substances such as glucose and proved their taste sense keener than man's.

Ample demonstration exists that fishes can remember. Experiments by several workers have established the retention of conditioned behavior for the following periods: Churchill—13 days; Goldsmith (1914)—18 days; Reighard—20 days; Russell (1931)—98 days.

Very stimulating results have been recently obtained by configurational or *Gestalt* psychologists. The work of Schaller (1926), Herter (1929), Perkins and Wheeler (1930) and Perkins (1931) introduces the conception that fishes can recognize and react to abstract relationships—that they can grasp “configurations.” The fishes in question were trained to react to such things as geometric figures of different sizes and colors or to relative light intensities. The experimenters ascribe this learning behavior to “insight” rather than to trial and error.

As to conditioned behavior of groups of animals generally, very little experimental work has been done on animals other than man. The great difficulty of establishing adequate controls for human subjects seems to be largely responsible for the widely disagreeing results obtained in human group experiments. Many such experiments have shown decided influences of competition, pace-setting, stage-fright and so on. Hudelson's study (1928) of the effect of class size on university instruction indicates, contrary to popular notion, that large university classes do not tend to lower teaching efficiency. Of 21 similar investigations summarized by Hudelson,

14 show no, or dubious, correlation between class size and efficiency, 5 show positive correlation, and 2 negative.

There is no question that a group of animals influences the individuals in it. Alverdes (1927) indicates that the young of animals and children eat more in groups than when isolated; that man and beast sing more vigorously in concert. Morgan (1900) tells of a mongrel pup whose I.Q. was boosted through association with dogs of superior intelligence. Experimenting with chicks he found that "If a group of chicks have learnt to avoid cinnabar caterpillars, and if then two or three from another group are introduced and begin to pick up the caterpillars, the others will sometimes again seize them, though they would otherwise have left them untouched." The writer has seen a similar influence working between two angel fishes (*Pterophyllum scalare*). One fish fed to satiety will refuse angleworms falling near it until the other fish attempts to snatch them. Often, in such a case, the first fish will then seize the worm and eat it.

Several observations have been made on apparent synchrony of rhythmic behavior in animals; these are adequately reviewed by Allee (1931). They show a widespread tendency toward group unity.

Studies on imitation in animals constitute a special approach to the field of group behavior. Clear evidence of imitation is found in monkeys (*Cebus* and *Macacus*) by Kinnaman (1902) and Haggerty (1909). The same imitative tendency is found in white rats and cats though not so pronounced (Berry, 1906, 1908). Conradi (1905) tells of the metamorphosis of the songs of English sparrows when reared with canaries.

The possibilities of communication between animals are largely unexplored. The experiments of von Frisch (1923a) with honeybees revealed that a marked bee that had discovered a watched source of pollen or nectar communicated this information to other bees within the hive by means of a kind of whirling dance; the dance varied according as the booty discovered were nectar or pollen.

The experimental study of group behavior in fishes is a new field. Parr's study (1927) of schooling behavior in the chub mackerel showed that visual stimuli provided the integrating factor. A fish temporarily blinded will neither school nor mill with others in the same aquarium. Bowen (1931, 1933) has shown that visual and

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thigmotactic responses were involved in the aggregating behavior of young catfishes (*Ameiurus melas*). Experiments done in this laboratory by Henderson, Miller, and Welty (all unpublished) have indicated an inhibitory influence of the group in conditioning the behavior of mudminnows. Because the author's experiment was introductory to those that follow in this paper, it is briefly reported herewith.

MUDMINNOWS AND GROUP INHIBITION

Experiment 1.—Mudminnows (*Umbra limi*) were distributed as follows in large (see Materials and Methods) aquaria the four sides of which were covered with black paper: one each in five tanks, two each in two tanks, four each in four tanks, and ten each in two tanks. Each tank held the same amount of aerated water. The fishes were conditioned to jump out of water for food held on the end of a feeding needle (see below) when a redlight showed 75 mm. overhead. They were also trained to refuse the food (dipped in acetic acid or composed of bits of rubber tubing) when exposed to a green light of equal intensity. The results at the end of 48 days of trials were inconclusive. No differential learning rates could be detected with certainty. When, however, the results were studied on a basis of jumps per fish per minute of exposure there seemed to be a slowing down in the larger groups. Whereas the isolated and also the paired fishes averaged about 20 jumps per fish per minute under the red light, the groups of four averaged 10.3 and groups of ten, 5.9 for the 48 days.

While a part of the slowing down of the groups was undoubtedly due to the lessened opportunity of jumping in a given time—two fish rarely jumped at once and three never did so—observations showed a definite antagonism between members of a group which prevented many otherwise possible jumps. As one fish would assume the characteristic jumping position another fish would often attack it with a vigorous jab in the belly. These results are mainly reported here because of their apparent disagreement with the general findings of later experiments.

MATERIALS AND GENERAL METHODS

The experiments that follow were performed between September, 1929, and September, 1932, at Whitman Laboratory of Experimen-

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tal Zoölogy, University of Chicago; at the Marine Biological Laboratory, Woods Hole, Massachusetts; and at Parsons College, Iowa. Except where stated otherwise they were performed at Whitman Laboratory. About 930 fishes were used, most of them goldfishes, *Carassius auratus*. The other species used were: the Pursy Minnow *Cyprinodon variegatus*, the Killifish *Fundulus heteroclitus*, the Lake Shiner *Notropis atherinoides*, the Paradise *Macropodus opercularis*, and the Zebra Fish *Brachydanio rerio*.

Goldfishes were used for most of the experiments because they were available in quantities throughout the year, hardy under laboratory conditions, and relatively active. Except in the case of *Fundulus*, sex was not determined; the goldfishes were immature, about 50 mm. long. Unless specific mention to the contrary is made below, all fishes were permanently discarded at the end of each experiment. To distinguish individuals in groups fishes were first marked with india ink injections (Keys, 1928) but it was found that the spots thus made faded in a month or two, so a system of clipping off bits of the caudal fin was substituted. In case a fish died during an experiment its record was used only for that period during which it appeared to be in active good health.

Temperature and light were not controlled excepting as the experiments were housed in laboratory rooms or in a greenhouse with steam heat under rough thermostatic control. Some of the early experiments were performed either in a dark room or at night so that a red-light stimulus might be used. It was found, however, that the light was either so bright that it apparently dazzled the fishes, or else so dim that the experimenter had difficulty distinguishing them. Furthermore the fishes appeared to be less active at night, or in the dark, and hence became conditioned less rapidly, so most of the experiments were carried on by daylight. A control experiment with the red-light stimulus showed neither positive nor negative phototropism.

Ordinary laboratory aquaria were used for most of the experiments. They were constructed of galvanized and painted angle-iron frames into which were cemented double-thickness sheets of window glass. The *large* aquaria used measured 26.5 cm. high, 26.5 cm. wide, and 30.5 cm. long, outside dimensions. *Small* tanks were 20.5 cm.

high, 22 cm. wide, and 25.5 cm. long. City tap water was used except in the experiments with marine species where running sea water was employed. Ordinarily the water was 18 cm. deep in large tanks and 15 cm. in small. Tanks were always cleaned between experiments and sometimes sterilized when fungus growth of parasites threatened. For the first experiments bubbling air, and in one instance small pots of *Vallisneria* were used to oxygenate the water, but this was later found unnecessary and was discontinued.

EXPERIMENTAL PROCEDURE

As the experiments progressed both the materials used and the experimental technique became considerably modified so that a general description of a typical experiment becomes difficult. This unfortunately makes necessary the inclusion of much descriptive matter. The method most generally used consisted essentially in offering a stimulus at one end of the aquarium to which the fish responded, when conditioned, by swimming (toward the stimulus, e.g.) from the other end of the tank through an opening in a barrier. The procedure followed in Experiment 2 will serve as an introduction to the remaining details of materials and methods as used in the early experiments. Modifications of procedure and apparatus will be explained later as necessary.

Experiment 2.—A battery of seven large aquaria was arranged on a waist-high shelf in a dark room. Each tank was filled with tap water to a depth of 18 cm. The front end (toward the experimenter) of each tank was covered with a removable piece of cardboard, the remaining three sides were permanently covered with black paper. Each tank was supplied with bubbling air. Into each of the seven tanks was inserted a screen barrier composed of one-eighth inch mesh galvanized wire (Fig. 1). It extended the full width of the tank and from the top to the bottom, located parallel to and 10 cm. from the front end of the tank. In the center of the screen was a conical opening that led from the rear chamber to the front one; the chambers were created by the screen. The cone gate or entrance was .65 cm. long with a circular opening 7.5 cm. in diameter where it fastened to the screen barrier and an opening 2.8 cm. in diameter at the smaller front end. A sliding metal plate controlled this opening.

Unselected goldfishes averaging 45 mm. in length (always excluding the tail-fin) were distributed in the tanks as follows: one fish in each of the first four tanks, two in each of the next two tanks, and four fishes in the last tank. The fishes were allowed to become accustomed to the tanks with the gates left open for seven days. Then those that happened to be in the front compartment were gently

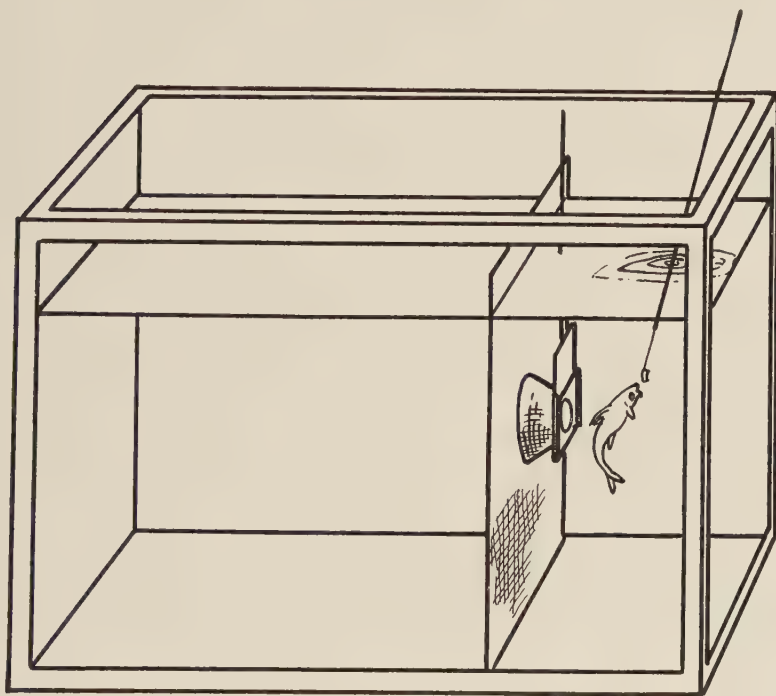


FIG. 1.—Cone-screen maze used in Experiments 2 to 8

maneuvered into the rear compartment and the gates were closed. On the ninth day the first trials were run as follows. The red light used in Experiment 1 was so placed that it shone directly into the center of the cardboard covering the front of the tank. Then the gate of the screen was opened and the cardboard removed simultaneously. Eventually the fish or fishes in the tank found their way through the opening by random movements. As soon as a fish passed through the cone-gate it was fed under water with a bit of

freshly cut earthworm impaled on the end of a feeding needle. This needle was composed of a stiff wire handle 23 cm. long and 1.2 mm. in diameter with a fine German silver bristle 5.8 cm. long and 0.3 mm. in diameter soldered to the handle. The meat was affixed so that it was easily removed. Where several fishes were in a tank the gate was left open and the light on until all the fishes had come through the gate and were fed. In group tanks it often happened that one or more fishes would swim back and forth through the gate after their initial performance. In such instances the fish was fed on its first performance but never on subsequent ones of that trial. The needles allowed controlled feeding so that each fish was fed only once in a given trial. A fish was arbitrarily considered through the opening when its dorsal fin had passed the plane of the circular opening at the outer smaller end of the cone. Fishes so located rarely if ever turned back. After all the fishes in a tank (or *the* fish in the case of isolated fishes) had come through the gate and were fed, they were gently maneuvered under the raised screen barrier into the rear chamber, the light was shut off, and the cardboard front and screen replaced. The screen was moved only at the end of a trial for returning fishes to the rear compartments. The fishes were never handled either between or during trials. After trials the tanks remained closed and in the dark until the next day when the above routine was repeated. Daily trials continued until the end of the experiment. The data obtained from this experiment consisted of the reaction time of each fish. This was the time that elapsed between the turning on of the light and opening of the gate in each tank and the time at which a given fish passed through the opening and was fed. The reaction time of fishes in groups was compared with that of isolated fishes on this basis.

GROUP LEARNING *vs.* ISOLATED LEARNING

Experiment 2.—The procedure followed in this experiment has just been given. A goldfish in the group of four died on the day of the third trial and its record was not used in determining means. A substitute fish was placed with the three survivors and its individual record figured in average computations only from the fifth trial on. To serve as a check on this group an auxiliary group of four fishes

in a tank was started on the thirteenth day (trial) of the experiment. The mean reaction times are given according to type of grouping in Table I. In all cases "mean reaction time" means the average reaction time of all fishes of a given class on a given trial. The ineffectiveness of continued conditioning after the sixth or seventh trial is especially noticeable. While the mean reaction time for the fishes in the auxiliary group of four shows superior speed of learning, the data from the original set-up furnish no evidence of a marked group influence.

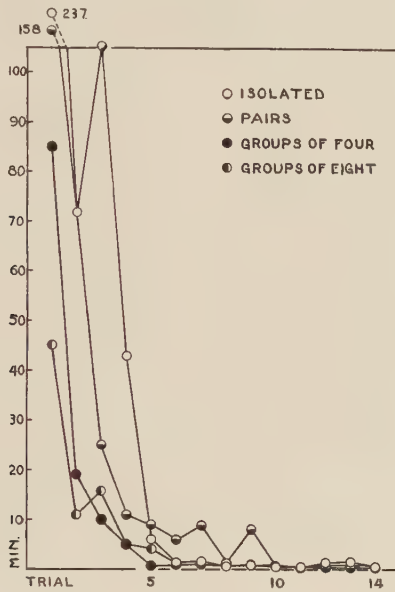


FIG. 2.—Mean reaction time for gold fishes in a cone-screen maze. Experiment 4

Experiment 3.—In this repetition of Experiment 2 the following modifications were introduced. The aquaria were arranged on a shelf in a greenhouse and cardboard covers were placed over them (in addition to the usual side-coverings) to eliminate algal growth. The red-light stimulus was made brighter. There were 15 tanks into which the fishes were distributed thus: one each in the first eight, two each in the next four, four each in the next two tanks, and eight in the last tank. Other conditions were as before. The brighter light seemed to blind the fish as they did not take the worm fragments

from the feeding needles immediately upon performing as they did before. No certain influence of the group is evident (Table I).

Experiment 4.—Fifteen aquaria with screens as before were set up in the greenhouse and the red-light stimulus discarded for daylight. Fish, distributed as in Experiment 3, were given a nine-day acclimation period in the tanks with the gates open. Trials were run daily. Small pots of *Vallisneria* were placed in the right rear of each tank

TABLE I
MEAN REACTION TIME OF GOLDFISHES IN A CONE-GATE MAZE
(Time is given in minutes and hundredths)

EXPERI- MENT NUM- BER	NO. OF FISH PER TANK	TRIAL NUMBER							
		1	2	3	4	5	6	7	8
2.	1	26.30	5.05	7.78	1.47	0.97	1.17	0.76	0.43
	2	38.41	13.34	16.84	3.99	1.75	0.58	1.22	2.81
	4	18.07	19.09	6.00	2.09	2.08	0.47	0.53	0.72
	4*	5.25	2.95	0.76	1.59	0.68	0.25	0.30	0.34
3.	1	88.84	18.51	13.97	7.49	6.28	3.18	7.42	4.09
	2	83.14	12.14	13.88	8.36	6.38	5.07	6.16	4.49
	4	132.00	16.97	7.83	6.58	3.74	3.99	6.78	3.75
	8	18.30	16.03	9.01	7.25	3.70	5.33	2.43	5.34
4.	1	237.00	71.61	105.23	43.16	5.92	1.22	1.41	0.45
	2	158.00	73.00	25.34	11.03	8.66	5.95	8.91	1.28
	4	85.00	19.09	9.95	4.92	0.63	0.91	0.74	0.55
	8	45.25	10.50	15.68	4.28	4.17	1.53	1.68	1.61
5.	1	284.00	118.33	44.26	38.75	19.00	3.26	10.50	2.76
	2	214.41	121.85	6.57	1.49	1.28	0.64	0.26	0.28
	4	13.50	14.17	4.58	2.01	1.42	0.26	0.22	0.36
	8	17.42	4.68	2.32	1.22	0.32	0.30	0.25	0.28

* Auxiliary group.

for aeration. The records of two of the isolated fishes were deleted because the fishes were refractory; they did not respond successfully within eight hours of presentation time on the first trials. The results of this experiment reveal a pronounced group influence; the larger the group the quicker the conditioning. Data are given for the first eight days in Table I and shown graphically for the first fourteen days in Figure 2.

Experiment 5.—This was a repetition of Experiment 4 with two minor modifications. Bubbling air was used for aeration. Instead

of giving daily trials in the same tank-order—1, 2, 3, 4, 15—each day, the order was now reversed daily: 1 to 15 one day and 15 to 1 the next. The results obtained corroborate those of Experiment 4; the larger the group the quicker the conditioning. A fish in the group of eight died on the day of the fourth trial; its record was ignored in final computations. Three fishes were mainly responsible for the greatly retarded mean reaction time of the isolated fishes. This same experiment continued on as another experiment in retention and the graph is shown in that connection in Figure 6. Data for this experiment are given in Table I.

INFLUENCE OF LEADERSHIP

Experiment 6.—This experiment was really run as two separate preliminary experiments to see what effect a trained fish might have upon its untrained fellows. In addition to the fifteen tanks mentioned above, two other similar tanks were arranged in the row each time in Experiments 4 and 5. Into these tanks (Nos. 16 and 17) were placed one and two previously trained fishes respectively. Also, with these trained fishes were placed new untrained fishes, one in each tank. These extra fishes were treated along with those in the regular experiments and in exactly the same fashion. A decided influence of leadership was apparent in the results. The untrained goldfishes in both types of tanks (tanks with one and with two trained fishes respectively) learned successful responses in about one-half the mean time for the groups of eight. Those fishes with two trained leaders each learned in less time than did those with one each.

Experiment 7.—In order to check the results of these preliminary experiments on leadership and to analyze the nature of leadership, a new experiment was arranged. Fifteen aquaria were placed in a row on a greenhouse bench with screens, water, air, black coverings, and cardboard fronts as before. Seventy-four goldfishes, after being marked, were distributed thus: Into the rear (larger) compartment of each tank were placed four unconditioned fishes. Into the *front* chamber of tanks 2, 5, 8, 11, and 14 was placed an unconditioned fish each. Into the *rear* chamber of tanks 3, 6, 9, and 12, along with the four unconditioned fishes, there was placed a trained fish each.

These latter fishes were obtained from tank 15 of the group-learning experiment (No. 5) which had ended but two days previously. All other fishes were from the same new stock and averaged 41 mm. in length. During a two-week acclimation period the gates were kept closed. The object of the experiment was to determine what influence might be exerted by a leader or conditioned fish that lives and reacts with the unconditioned group as compared with the influence of a fish already through the barrier that acts merely as a visual stimulus or a lure. The tanks that contained four unconditioned fishes only served as controls. The untrained "lure" fishes stayed in front of the barrier screen both during and between trials whereas the conditioned leaders performed with their untrained fellows each day—generally ahead of them of course. The leader was always fed as soon as it performed; the lure fish was fed only after the first untrained fish in its tank had reacted and was fed. The removal of the front cardboard with the subsequent penetration of daylight into the tank, and the opening of the gate of the screen served together as the stimulus. While in these daylight-stimulus experiments the fishes were probably able to see the experimenter, great caution was exercised to prevent movements that might act as stimuli that would either enhance or inhibit reactions of fishes. The results of this experiment (Fig. 3*A*) seem to indicate that leadership stimulates learning and that it has an influence over and above that of a mere lure. The reaction time of the leaders is of course not included in computations.

Experiment 8.—Well-trained fishes from Experiment 7 were used as leaders in this experiment. All other fishes were new. After a fourteen-day acclimation period the trials were run as before. The results, given in Figure 3*B*, show a decided influence of leadership. Excepting the records for the fifth trial on which the mean reaction times of the two were nearly identical, the group-plus-leader fishes reacted in less time than the controls (and also the group-plus-lures) on each of the first eight trials; the curves reveal that these are the significant trials. This implies that the training significance of the leaders depends not merely on their presence on the opposite (front) side of the barrier but on their total reaction.

Experiment 9.—Three major modifications were introduced in this

experiment. First, the fishes were grouped differently. An objection may be raised against the variation in group size in the two previous experiments. The groups of experimental fishes contained a total of five fishes (four plus a leader or a lure) and the controls contained only four each. In the present experiment there were but two varieties of groups—control groups of three unconditioned fishes each and experimental groups of two unconditioned fishes plus one conditioned fish. There was no acclimation period; the fishes were given their first trial about half an hour after being placed in the

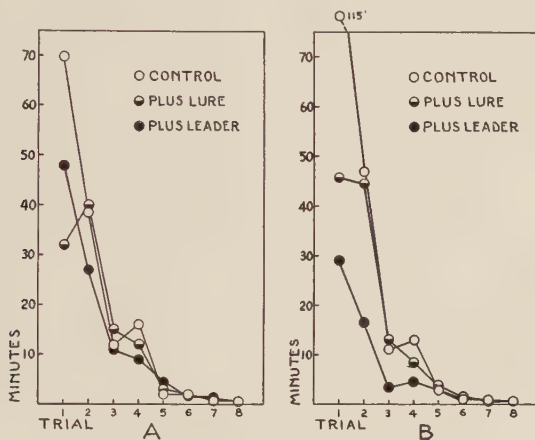


FIG. 3.—Mean reaction time of goldfishes in a cone-screen maze showing influence of leadership. A, Experiment 7; B, Experiment 8.

aquaria. A third modification was the substitution of a flat-gate screen for the cone-gate screens. Being bottom feeders the goldfish found the bottom opening in the new screens by random movements in less than the time customary with the elevated gates. This type of screen was used later in group-cohesion experiments and is illustrated in Figure 4. In the present experiment the screen barriers were used singly in each tank. They were composed of one-eighth inch wire screen and were placed parallel to and 7.5 cm. from the front end of small tanks. In the lower right-hand corner of each screen was placed a 5×5 cm. square opening with a metal sliding door as before. The water in each tank was kept at a depth of 15 cm. The fishes averaged 45 mm. in body length. The results confirm

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those of the two previous experiments. The mean reaction time of the control fishes was more than treble that of the experimentals on each of the first five days.

Several attempts were made to find a statistically reliable method for determining the significance of differences in the so-called learning curves. The difficulties involved seem largely due to our ignorance of what learning is. It is impossible to ascribe the difference between two given curves to difference in mean learning ability. Other variables than that of learning are involved. First, the motivations provided by the original conditions of the experiment undoubtedly drew forth variable mean responses from the contrasted groups. A second variable resulted from the varying mean capacities of the two types of groups to learn the required behavior; this by virtue of direct influence of type of grouping, and indirect influence of variable motivation, on learning rate. Third, it is probable that the contrasted types possessed variable mean abilities to retain what they learned. Mean reaction times depended on all these influences and possibly others.

However, even though one cannot distinguish how much of the difference in performance between the experimentals and controls is due to learning, one can figure whether or not the daily difference between the mean reaction times of the contrasted groups possesses statistical significance. Student's (1925) method was used in computing the statistical probabilities in Table II. The figures represent the number of chances, on a basis of one, that random sampling would give as great a variation in behavior.

A more significant view of the reality of the differences in conditioned behavior between the contrasted groups can be had by smoothing and weighting curves of several similar experiments. This method is contrived to bring out the significance of those portions of the curves which should be most expressive of difference in learning rates.

Obviously the mean results of the first trial in any experiment reveal nothing about learning. Differential learning rates, if any, should show up with progressive significance from the second trial on. But since both groups, experimental and control, eventually reach the same efficiency of performance, i.e., their curves flatten out

together—any such progressive difference between them is obliterated. One must therefore look about midway between the first trial of any experiment and that trial on which the two curves later coincide for an expression of the most significant difference between the two curves.

The mean reaction times for the contrasted classes (isolated versus groups of four in this case) for the first five days of a given experiment were determined. These mean reaction times were then weighted so as to emphasize that period during which the curves should show the most significance in learning divergence. The mean

TABLE II

STATISTICAL SIGNIFICANCE OF DIFFERENCES IN REACTION TIME OF FISHES
IN LEADERSHIP EXPERIMENTS FIGURED ON A DAY-BY-DAY BASIS

EX- PERI- MENT	SIGNIFICANCE BETWEEN REAC- TION TIME OF:	DAY				
		1	2	3	4	5
7.	Plus leaders and controls	0.150	0.336	0.623	0.046	0.622
7.	Plus leaders and plus lures	-0.106	0.844	0.151	0.434	-0.921
8.	Plus leaders and controls	*0.0000	*0.011	*0.020	*0.022	0.921
8.	Plus leaders and plus lures	0.209	*0.022	*0.012	0.127	0.844
9.	Plus leaders and controls	0.154	*0.0004	*0.0003	*0.007	*0.013

* Statistically significant.

reaction time for the isolated fishes on the first day (in a given experiment) was unweighted; that of the second day was doubled; that of the third day was trebled; that of the fourth day was doubled; that of the fifth day was unweighted. These values were then added. The same weighting applied to the compared groups of four so that two figures finally represented the performances of the two contrasted groups for the first five days of that particular experiment. Such pairs of figures were obtained for experiments 2, 3, 4, 5, and also 16, 17, and 18. Applying Student's method to these seven pairs of figures gave probabilities of 0.020 which indicate statistical significance. The significance does not apply to difference in learning ability directly but is very possibly an oblique indication of its existence.

For the remaining experiments significance will be read directly from the tabular data or from the graphs.

GROUP-COHESION EXPERIMENTS

These experiments were designed to reveal what part, if any, a possible group-cohesive force might play in the conditioning of fish behavior. The groups of control fishes were trained to choose one of

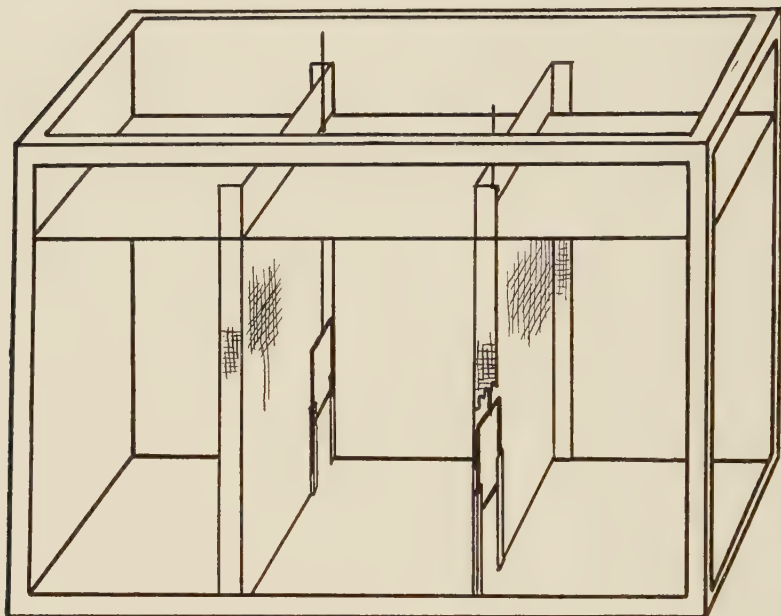


FIG. 4.—Simple maze for studying group cohesion. Experiments 10 to 15

two doors in a simple maze whereas the experimental fishes were conditioned to choose both of the two doors; i.e., certain marked fishes in the group always chose one door and the rest in that group always chose the other door. The control groups reacted intact; the experimental groups had to split. Figure 4 shows the type of maze used. At the start of the trials both the experimental and control groups were placed in the central compartment of each tank. After the gates were opened at each trial, the fishes by random movements eventually found their way through one gate or the other. If a given fish went through the gate which the experimenter had arbitrarily

selected as the correct gate it was fed. Otherwise not. Both gates were left open on every trial until the last fish of each group had performed successfully and was fed. The groups were then gently driven to the center compartment and the gates were closed until the next (daily) trial. The "correct" gate for a given fish remained the same throughout the experiment. Since different sized aquaria and different stimuli were used, further details will be given under specific experiments.

Experiment 10 (Marine Biological Laboratory).—Aquaria 49 cm. long, 35 cm. wide, and 33 cm. deep with cypress ends and bottoms were used; running sea water was kept at a depth of 32 cm. throughout the experiment. Two screen barriers were so placed as to divide each tank into three equal-sized compartments. (See Fig. 4.) Gates were placed in the bottom of each screen as before; the openings were 5 cm. square and were set in 2 cm. from the edge of the tank—the front gate on the lower left-hand side, the rear on the right. The experiment was conducted in a dark room. A 60-watt Mazda lamp with reflector was hung 35 cm. over the center of each tank to serve as a stimulus during trials. The tanks were so sheltered that only the fishes being given their trial were illuminated.

Sixteen killifish (*Fundulus heteroclitus*) averaging 70 mm. long were marked with India-ink injections and distributed four each in four aquaria. In the first tank all four fishes were rewarded only when they came through the gate toward the front of the tank; in tank two, fishes A and B performed successfully by coming through the front gate and C and D by passing through the rear gate; in tank three all four fishes were trained to pass through the rear gate; in tank four the group split as in tank two. Tank two contained exclusively females, the other tanks contained only males. The fishes in each tank were allowed a two-day acclimation period with gates open. The results showed no significant difference in behavior between the contrasted groups.

Experiment 11 (Marine Biological Laboratory).—This was a repetition of the preceding experiment using, however, *Cyprinodon variegatus* instead of *Fundulus*, and clipping tails for identification instead of using ink spots, which became infected with a luminescent mold or bacterium. The results of this experiment showed a definite separa-

tion of the two mean reaction time curves (Fig. 5). The cohering groups apparently learned in less time than the separating groups.

Experiment 12 (Parsons College).—Large aquaria were fitted with screens similar to those in Experiment 11 so as to divide the tanks into thirds. The gates were 5×5 cm. The stimulus was a red light in a wooden box presented at the front end of a given tank during trials. All trials were run at night. Goldfishes averaging 40 mm. in length were used; their fins were clipped for individual identification as before. Results for this experiment showed no significant difference between the cohering and the splitting groups in rates of condi-

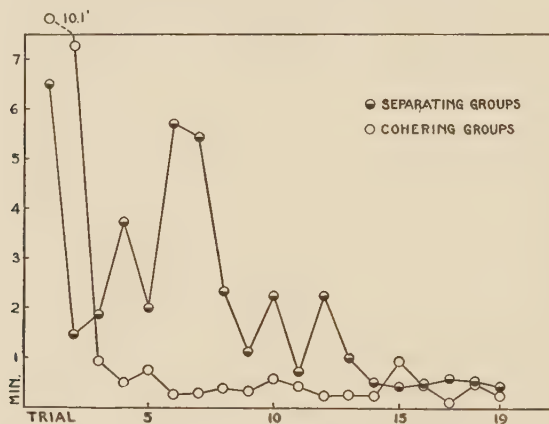


FIG. 5.—Mean reaction times for *Cyprinodon* in group-cohesion experiment

tioning. The behavior of the fishes was probably influenced through their being exposed to an active laboratory environment between trials.

Experiment 13.—Eight large aquaria were each divided into three equal chambers by screen barriers as before. The gates were 5×5 cm. square and were set in 12 mm. from the edges of the bottoms of the screens. The front gates were to the experimenter's left and the rear to his right. As before, all tanks were covered with black paper on the two sides and the rear; the front was covered with a removable card board. This experiment and all subsequent ones reported here were performed at Whitman Laboratory. A red light placed against the front glass of each tank (in turn) served as a stimulus.

The four marked gold fish in each tank were given a three-day acclimation period with gates open. Daily trials continued for 37 days; the fishes were then transferred to another experiment on the effect of feeding which will be treated below. Fishes in half of the tanks separated for a successful performance while those in the remainder of the tanks were trained to pass through only one of the possible two openings. Excepting for trials 1 and 2, the cohering groups reacted successfully in less time than did the splitting groups until the twelfth trial; from then on both groups performed about equally well. This indicates that group cohesion was a factor in stimulating the conditioned behavior of these fishes.

Experiment 14.—In this attempt to discover the rôle of cohesion in group-learning three modifications were introduced. Small tanks were used and daylight provided the stimulus. The split groups were conditioned to divide one to three instead of two to two. The cohering groups reacted as formerly. During this experiment, which ran 18 days, the excessive summer heat caused so many fishes to die that the records of half of the tanks had to be thrown completely out. The remaining data showed no cohesion advantage.

Experiment 15.—This was essentially a repetition of Experiment 14 with one variation: three 45 mm. goldfishes were placed in each small tank instead of four. In the separating groups one fish reacted in an opposite direction from the remaining two. Possibly due to records of refractory fishes in tank 1, no significant differences in the mean reaction time curves of the two types of groups were found.

EXPERIMENTS IN RETENTION

These experiments were set up to determine whether the grouping of fishes had anything to do with the retention of conditioned behavior. Goldfishes approximately 45 mm. in body length were used throughout and all experiments were performed in the Whitman Laboratory greenhouses.

RETENTION THROUGH TIME

Experiment 16.—An attempt was made to determine not only whether grouping influenced retention but whether the influence, if any, came from learning as a group, from retaining as a group, or from both. Thirty-two goldfishes were distributed in twenty small

tanks thus: tanks 5, 10, 15, and 20 contained four fishes; each of the other tanks, one. In each tank was placed a single flat-gate barrier similar to those of the cohesion experiments. Each screen had a 5×5 cm. gate in the lower right-hand corner and was placed parallel to and 10 cm. from the front of the tank. The fishes were allowed four days of acclimation with the gates open and one day with them closed. They were then trained through 29 daily trials to come through the gates for food. Characteristic learning curves resulted in which the groups of four excelled the isolated fishes as in earlier experiments. Then, just after the twenty-ninth trial the fishes in two of the four group tanks were isolated into individual tanks; the other two groups remained intact. On the other hand, eight of the fishes that had been trained isolated were gathered into two groups of four each in two tanks; the other eight isolated fishes remained as before. All fishes remained in the same type of screen-barrier tanks as those in which they had been trained. Merely the grouping arrangement had been changed. Every fish in every tank was picked up with a net whether it was shifted to a new tank or not. The fishes were then given a four weeks' vacation from visual stimuli, trials, and feeding. At the end of this time they were given three daily trials. Seven fishes died during the retention period, so very little reliance can be placed on the data obtained. The results showed no certain influence of the group on retention and also showed very poor retention, particularly on the part of the grouped fishes.

Experiment 17.—This experiment was identical with Experiment 16 except for these changes: the fishes were allowed a ten-day acclimation period and a two weeks' vacation from trials and feeding just after the tenth trial. Their original grouping was retained throughout the experiment; no shift was made either before or after retention. Apparently the retention period was too short to test for an outstanding difference between group and individual retentiveness; none is discernible. Both the isolated fishes and the group retained their conditioned behavior perfectly after the two weeks' gap. In the preceding experiment with the four weeks' gap almost without exception the fishes performed less well after the retention period than they did on the very first trial of the experiment.

Experiment 18.—Twenty-four goldfishes were placed into sixteen aquaria with flat-gate screens such as those used in the previous experiment. Three fishes were placed in each of tanks 4, 8, 12, and 16. All other tanks contained one fish each. After an eight-hour acclimation period behind closed gates normal feeding trials were begun. After the fifth daily trial the fishes were “fed” a small bit of red rubber tubing about the size of the usual bit of fresh worm to which they had become accustomed. There was no retention period. The rubber reward continued for eleven daily trials. The results of this experiment showed indications of better retention by the fishes in groups than by the isolated fishes but not significant probabilities of better group retention.

RETENTION IN SPITE OF PUNISHMENT

Experiment 19.—This was a continuation of Experiment 5. Only one modification was introduced: from the eleventh trials onward the fishes were “fed” bits of freshly cut worm that had been soaked in glacial acetic acid just before the feeding. Other conditions were the same. At first the fishes persisted in biting the acid meat upon performing the cone-gate maze. Their violent expulsive mouth movements showed however that it was no reward. They gradually lost their avidity for the doctored meat and some of them eventually refused to come through the gate in the allotted half-hour of presentation time. If a fish did not respond within half an hour the gate and tank were closed until the next daily trial and that fish arbitrarily credited with a reaction time of half an hour even though it would have taken more time than that. This had to be done because in this experiment, time was not available for indefinite waiting. Many fishes persisted in coming through the gate for a long time after they refused to bite or even swim toward the acetic worm. Fishes that did not react within half an hour on three consecutive days were ignored in further trials except to be credited with a half-hour reaction from then until the end of the experiment. This was done because a fish that would not react for three days might lose its conditioning against the punishment, as several apparently did, and begin coming through again. Seven of the thirty-two fishes died during the retention part of the experiment and their records were

incorporated in the final reckoning only for those periods during which they seemed to be in good health. The results of this experiment show that all of the groups of fishes—twos, fours, and eights—retained conditioning in the face of punishment better than did the isolated fishes. The results seem to bear out those of Experiment 18 on retention through time. It is quite possible, however, that the rise in the curve of the isolated fishes after the application of acetic acid

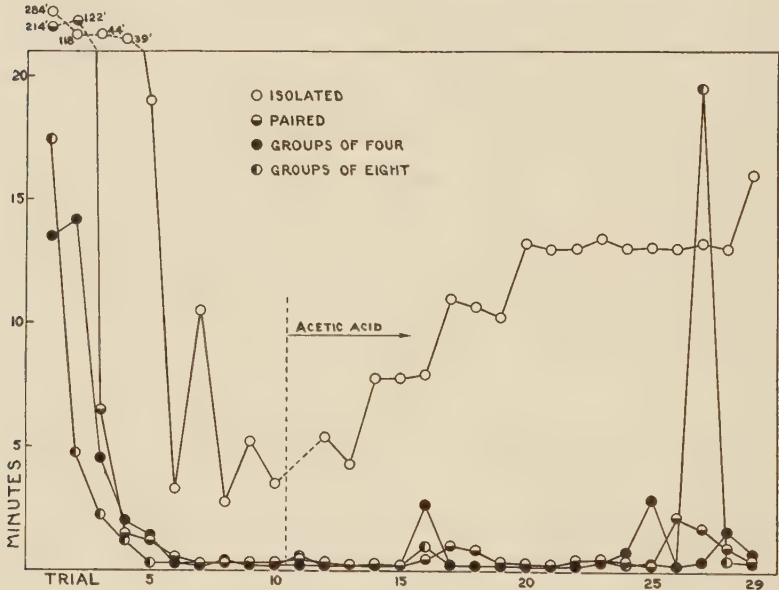


FIG. 6.—Mean reaction times of goldfishes on successive punishing trials. Experiment 19.

acid is in some way connected with their slower original conditioning. The peak in the curve of the group of eight on the twenty-seventh trial (Fig. 6) is unaccountable. All the fishes remained huddled in one corner of the tank for ten minutes after the gate was opened, then they slowly and cautiously began to swim about. All six of them (two had died) came through within two minutes of one another.

Experiment 20.—In the same way, this was a continuation of Experiment 17. After the twenty-eighth trial of the original experi-

ment worms were dipped in glacial acetic acid before being offered the performing fishes. Since 11 of the 32 fishes died by this time the results are not of much significance. Curves of isolated and grouped fishes crossed frequently and probably indicated erratic behavior on the part of both. The results do not corroborate those of the previous experiment. Data are not given.

Experiment 21.—Taking advantage of the fact that fishes have to learn to take food from the feeding needle, an effort was made to see whether groups influenced the retention of this conditioned behavior. Eighteen 45 mm. goldfishes were distributed in 12 small tanks: three fishes each in tanks 4, 8, and 12; one each in all the other tanks. The tanks were shielded from one another with black paper, filled with 15 cm. of water, and contained no screens. As usual the stimulus was the opening of the front cardboard which let in additional daylight. The fishes were conditioned to eat the bit of worm from off the needle near the surface of the water. After 21 such trials each fish was presented with a bit of worm that had been dipped in acetic acid. This "food" was placed approximately two inches in front of each fish so that it could not avoid seeing it. Every fish in the experiment was offered 60 such pseudo-feedings: 30 on the first day of acid trials, and 10 on each of the three following days. The reactions to the acid food varied all the way from seizing it to avoiding it by swimming away. By assigning arbitrary numerical values to each type of response a quantitative estimate of retention of the feeding habit was arrived at. There was no significant difference between isolated and grouped fishes in the first ten acid trials, but in both the last ten acid trials and in the total performance for the 60 acid trials the groups retained their conditioning about 11 per cent better than did the isolated fishes.

EXPERIMENTS IN MOTIVATION

In the foregoing experiments the food reward served as the motivating factor that stimulated learning. The group itself seemed also to provide a motivation that the isolated fishes lacked. The experiments in this section form an inquiry into the nature of these two moving factors and some of their interrelationships.

EXPERIMENTS IN FOOD DRIVE

Experiment 22.—This was a continuation of Experiment 13 under the section on Group Cohesion. From the twelfth to the thirty-seventh daily trials the fishes showed no appreciable increase in learning as revealed by their mean reaction time. On the thirty-eighth day the fishes in all tanks were given seven trials in as rapid succession as possible with normal feeding at each trial. The first tank was given one trial, and then the second tank one, then the third tank, and so on. As soon as the last (eighth) tank in the row had had its trial, number one was again opened, the fishes stimulated, and fed when they reacted. Then tank one was closed and tank two opened and run; and so seven times through the series of tanks. Then, after skipping a day, the same fishes were given eight trials in rapid succession but this time with no feeding. As a check on the results obtained, the fishes were given a day's vacation and then tested again, twice in succession with feeding and on the next day twice in succession without feeding. Results: on successive feeding trials the fishes reacted more and more slowly until, during the later trials, they became very sluggish and seemed to perform only by virtue of random movements. Toward the end of the feeding trials several fishes failed to take the offered bit of fresh worm. No appreciable difference appeared between the performances of the cohering and separating groups. The reaction time of the first of the consecutive no-feeding trials was about the same as that of an average normal trial. But the seven subsequent no-feeding trials proved to be the quickest and most consistent of the entire experiment. The check trials made two and three days later showed the same general results. The curves for this experiment are shown in Figure 7.

Experiment 23.—The same technique was used to determine the effect of feeding- and non-feeding trials in a continuation of Experiment 17 after the 15th trial. Of the original 32 fishes, two isolated ones proved refractory and did not respond within half an hour, two other isolated fishes had died, and two from the groups had died. These fishes were not involved in this experiment. Six consecutive feeding trials and six consecutive trials without feeding in general repeated the results of the foregoing experiment. The "best" performance of the 36 trials of the whole experiment came during the non-

feeding trials; the "worst," during the consecutive feeding trials. No differential effect on the groups and isolated fishes was evident. Data are omitted for lack of space.

EXPERIMENTS IN FOOD CONSUMPTION

Experiment 24.—A preliminary experiment was undertaken to see whether the group affected the food consumption of goldfishes. Medium-sized earthworms were cut into bits about 2 mm. long by means of a set of 12 parallel mounted razor blades. These bits were thoroughly rinsed in tap water and then fed to medium-sized goldfishes distributed singly, in pairs, and in groups of four in aquaria that each contained the same amount of water. The pieces of worms

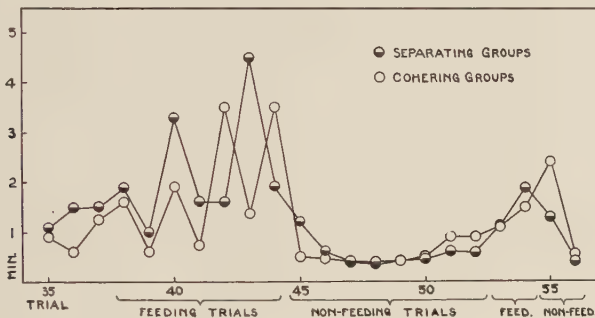


FIG. 7.—The effect of giving and withholding reward in successive trials with goldfishes. Mean reaction time. Experiment 22.

were counted when they were placed in each tank and the uneaten surplus counted when removed at the end of an allotted feeding period of one-half hour. Even though the clitellum and two ends of each worm were not included, it was impossible to insure equal-sized pieces—a thing most necessary for determining quantitative food consumption. This fact coupled with early deaths among the fishes invalidated what results there may have been. All that can be said is that there was a rough indication that the individuals in the groups ate more per fish than did the isolated fishes.

Experiment 25.—Since earthworms did not prove satisfactory as a measurable food, *Daphnia* were substituted and a smaller species of fish used to cut down consumption. The lake shiner *Notropis atherinoides* served very well for this experiment provided it was kept

cool. Each of seven small aquaria used stood in cool running water on a water-table; aeration was provided by bubbling air. Four shiners averaging 46 mm. in length were placed in one tank holding 8 liters of water; four fishes averaging 45 mm. were placed two each in two tanks of water that each held 4 liters of water; four fishes averaging 46 mm. in length were placed singly in four aquaria that each held 2 liters of water. All tanks were visually isolated from each other by black-paper wrappings. The *Daphnia* used for feeding were sifted so that only the larger sizes were retained. Into each tank was placed at each feeding a greater number of counted *Daphnia* than the fishes in it could consume in an hour. At the end of an hour's feeding the surplus was removed and counted, the difference between the two counts being the number of crustaceans eaten by the fish or fishes in a tank. The result of six days' feeding, one hour each day, revealed that the most food was consumed among the fishes in the group of four. Each fish in the group ate on the average twice as much as the average fish among either the isolated or the paired fishes.

Experiment 26.—Thirty-one paradise fishes, *Macropodus opercularis*, were accurately measured by means of what were essentially photographic contact profile silhouettes on bromide enlarging paper. Of these fishes twenty-four were selected because of their similar sizes and were distributed in glass crystallizing dishes thus: four fishes each were placed in two vessels containing 5 liters of water each; two fishes each in four vessels containing $2\frac{1}{2}$ liters of water each; one fish each in eight vessels each holding $1\frac{1}{4}$ liters of water. The fishes in the groups of four averaged 28.0 mm. body length; those that were paired, 27.8 mm.; the isolated fishes, 27.8 mm. Black paper prevented extraneous visual stimuli and cardboard tops prevented the fishes from jumping out of the shallow dishes and foreign matter from dropping in.

Live *Daphnia* too large to pass through a wire screen 16 meshes to the inch were used for daily feedings. They were counted out into small beakers with a mouth-controlled pipette and then poured into a given vessel holding the fishes. At the end of exactly an hour the *Daphnia* remaining in each tank were removed with the pipette,

counted, and discarded. Feces were also removed by siphoning and the water-level was restored. The difference between the two counts for a given tank revealed the number eaten. Tanks were fed in rotation and the direction was reversed daily: one to fourteen one day, fourteen to one the next. The experiment continued through 33 daily feedings. In ten instances feedings for one day, and in two instances feedings for two consecutive days, had to be omitted to allow the supply of *Daphnia* to catch up with the fishes' appetites. The results show rather clearly that being in a group increases a fish's food consumption. For the first 22 feedings the fishes in the groups of four ate more sifted *Daphnia* per fish than did the isolated fishes on the average, and they exceeded the consumption of the paired fishes every day of the experiment but the third. From the twenty-third day on the food consumption of the isolated fishes and that of the members of the groups of four was about the same. Very few dead crustaceans were removed from the feeding vessels; the fishes usually ate all that they attacked. Where dead ones were left they were counted as live animals if they were whole; otherwise they were estimated as fractions of one animal.

Experiment 27.—Twenty-four zebra fishes, *Brachydanio rerio*, were measured in a narrow glass cell with a metric scale and then distributed in 14 crystallizing dishes as above. The two groups of four were in 2,600 cc. of water each, the four groups of two in 1,300 cc. each, the eight isolated fishes in 650 cc. each. Other conditions matched those of the preceding experiment. The *Daphnia* used were such as would pass through a 16-mesh-per-inch screen but not through an 18-mesh screen. The fishes were allowed to feed an hour. After the twelfth consecutive day of feeding the isolated fishes were gathered into groups of four and the groups of four were isolated into eight vessels. The original relation between size of group and amount of water was retained until the eighteenth feeding; from then on each tank contained the same amount of water—2,600 cc. The fishes were shifted back to their original groupings after the twenty-third feeding. Between the sixteenth and seventeenth feedings there was a three-day gap to allow *Daphnia* to multiply. Four fishes died during the experiment; all of the fishes were rather thin at the beginning.

The results (Fig. 8) show that grouping the fishes together undoubtedly increased their food consumption. Each day the isolated fishes averaged fewer *Daphnia* per fish than did the fishes in the groups of four. The eating of the paired fishes was rather irregular, starting in at first between the other two types of groupings and ending above both in quantity consumed. Equalizing the amounts of water in each vessel seemed to increase the food consumption of the isolated fishes more than it did that of the pairs or groups. Shifting groups showed conclusively that differential consumption

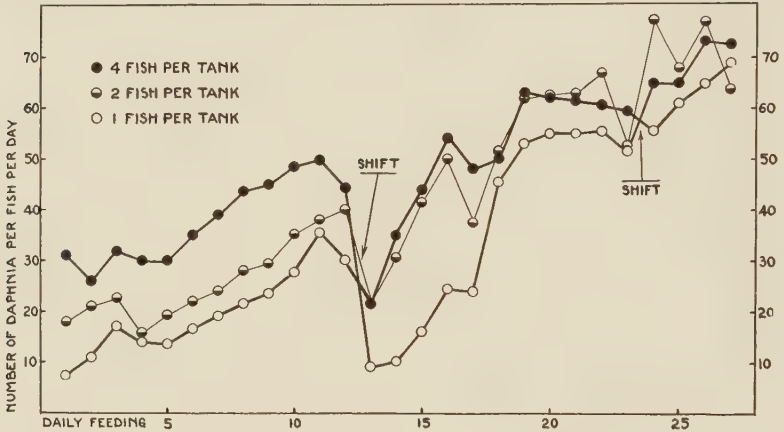


FIG. 8.—The effect of grouping on food consumption in zebra fish

did not depend on inherent individual appetite or size of fish but primarily on grouping.

Experiment 28.—Sixteen goldfishes of about 37 mm. body length were accurately measured by means of photographs of equal magnification and then placed in ten crystallizing dishes—four each in two of them and one each in the remaining eight. There were two litres of water in each dish. The fishes were nearly balanced as to length: the isolated fishes averaged 36.97 mm. body length and the grouped fishes 37.10 mm. A shift in the grouping later gave this slight advantage in size to the isolated fishes for the significant part of the experiment. The fishes were fed for one hour daily with all the large *Daphnia* (too large to pass a 16-mesh screen) they would eat. Rather than not feed the fish when the supply of *Daphnia* ran low, a sub-

stitute non-measurable diet was used. It was composed of one-half part dry rolled oats and the other half a prepared laboratory fish food containing dried shrimp, calves liver, eggs, flour, baking powder, ordinary salt, and magnesium sulphate. The fishes were fed this food on these days of the experiment: 17, 18, 19, 21, 22, 24, 25, 27. At the end of each hour's feeding the surplus was siphoned off. After three days of feeding the groupings were shifted: the isolated fishes were placed into groups of four per vessel and the grouped fishes were isolated. The results (Fig. 9) verify those of preceding experiments. The fishes of the groups of four consumed more

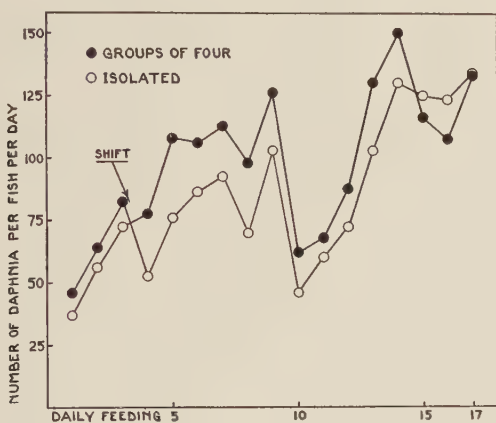


FIG. 9.—The effect of grouping on goldfish eating. Experiment 28

Daphnia every feeding except the last three. A possible explanation of this inversion in consumption at the end of the experiment is that the *Daphnia* became so numerous in the tanks of four that they presented too many stimuli; the fishes were observed to take after an isolated crustacean and eat it whereas a dozen or so in its immediate field of vision seemed to offer conflicting stimuli that blocked the feeding response. Working on such a hypothesis the experimenter tested the two groups thus on the last day: one group of four was given its usual quota of *Daphnia* all at once in the customary manner, the other group was given only a hundred at a time. As it exhausted these another hundred was poured into the tank, and so on. This prevented the *Daphnia* from becoming too concentrated in the

latter vessel, especially during the early part of the feeding hour. The isolated fishes were fed as usual. Whereas the control group (fed in the same manner each day) ate 64 more *Daphnia* this day than it had on the previous day, the experimental group ate 140 more on its second day. As in the foregoing experiments, the shift in grouping shows conclusively that the differential consumption is a matter of grouping and not one of inherent size of appetite. Precise measurements of the fishes showed that although the members of the groups ate more than did the isolated fishes, they grew significantly less.

ON THE EFFECT OF SEEING OTHER FISHES PERFORM A MAZE

Observations made during many of the above experiments tended to substantiate an explanation of group cohesion based largely on an interplay of visual stimuli. An experimental attempt was made to isolate and evaluate this factor by testing whether allowing fishes to watch other trained fishes run a maze influenced their ability to master it afterward. That is, is there a tendency toward imitation in fishes? The apparatus used (Fig. 10) consisted of large aquaria divided into two chambers, one narrow and one wide, by a glass partition extending from the front to the rear of each tank and from the bottom approximately to the top. The narrow compartment was 6.5 cm. wide and the wider one 9.5 cm. In four of the tanks this partition was painted black and weathered (to remove oils), in the other four it was left clear. Ten cm. from the front end of the larger chamber was placed a typical flat-gate screen barrier with a 5 cm. opening at the lower right-hand corner against the glass partition. Heavy airplane celluloid sliding doors were used in place of the less smoothly operating metal ones. The experiment consisted in allowing untrained fishes in the smaller chamber to see trained fishes perform in the larger one on the other side of the partition, and then, after removing the trained fishes, placing the untrained fishes in the larger chamber to see if they profited by their observations. The tanks with opaque glass were controls. Trials were made in daylight.

Experiment 29.—Four 45 mm. goldfishes were placed in the large chamber of each of the eight tanks. The two types of tanks were arranged alternately in a row. After 11 days of training the 32 fishes averaged 22 seconds reaction time. Unselected, untrained 45 mm.

goldfishes were then placed, one each, in the smaller chamber of each tank. Only in tanks 1, 3, 5, and 7 could they see through the glass partition. One hour after the new fishes had been introduced the usual trials with the trained fishes were resumed with this difference: when they came through the gate they were not fed. Otherwise they were treated exactly as they had been during the training

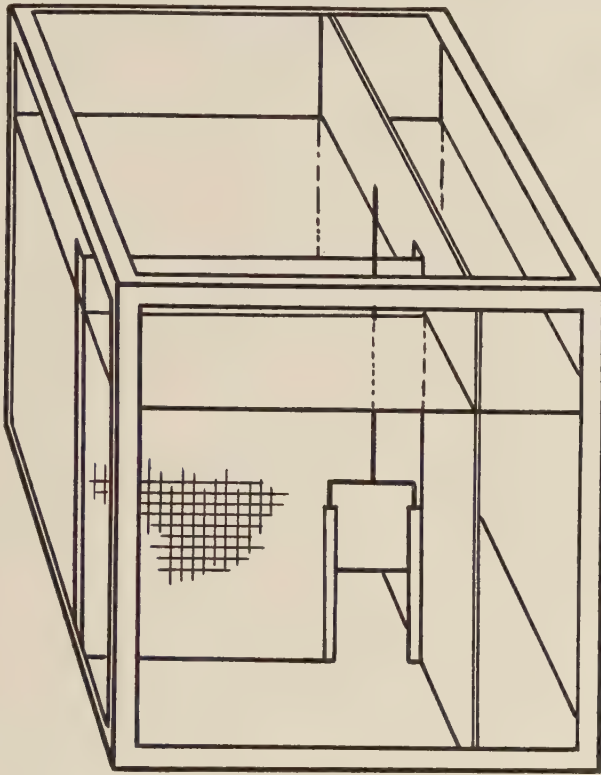


FIG. 10.—Type of aquarium used in Experiments 29 to 33

period. Ten such no-feeding trials were run in the next four days; then these trained fishes were removed and the untrained fish in each tank was shifted from the smaller chamber into the just vacated larger chamber. Four hours after this shift the new fishes were given their first trials. The cardboard fronts were removed, the gates opened, and the fishes fed bits of worm from the feeding bristle upon successful performance. Trials continued three days only. On the

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first day the fishes in the clear-glass tanks (that had been able to see the trained fishes perform) reacted with a mean time of 30.80 minutes, on the second day 4.74 minutes, and on the third day 4.59 minutes. The fishes in the opaque-glass tanks responded less rapidly: on the first day the three fishes in tanks 2, 4, and 6 together averaged a reaction time of 102.00 minutes while the fish in tank 8 did not respond in over 4 hours. On the second day all these fishes did not come through in over 80 minutes of stimulus presentation. On the third day the fish in tank 4 came through in 8.98 minutes but the other three fishes did not come through in over 80 minutes. The results are at least indicative of faster conditioning among the fishes that could see their trained fellows perform.

Experiment 30.—The trained fishes of the previous experiment were used as pace-setters for this one. After these trained fishes were again conditioned so that they responded in less than one minute (mean reaction time: those in clear tanks—29.0 seconds; those in opaque tanks—37.2 seconds) *three* new untrained fishes were placed in the small compartment of each tank. After four hours' acclimation first trials were run. The trained fishes reacted as before, only they were not fed. All tanks were given one trial the first day, seven the second, and two on the third day—ten in all. A slight slowing down of the reaction time of the trained fishes occurred, possibly because they were not fed when they responded. On the last trial, however, their mean reaction time was less than a minute. Then they were removed from the tanks and the untrained fishes shifted from their small chambers into the vacant large ones as before. An hour later they were given their first trials. They were fed as they responded successfully. The mean reaction times of the two types of groups shows a slight advantage for conditioning correlated with having lived in the clear-glass aquaria. See Figure 11.

Experiment 31.—This was a repetition of the above experiment with two changes. Twenty "pre-conditionings" were given the untrained fishes, i.e., those trials during which they observed (or not, in the case of fishes in the opaque tanks) their trained fellows through the glass partitions. The trained pace-setters were fed upon every successful response; this probably prevented the slowing down of the reaction time of the trained fishes. The mean reaction time for their last five pre-conditioning trials was roughly 15 seconds. An

attempt was made to prevent differential stimuli resulting from varying presentation time by keeping open the opaque-glass

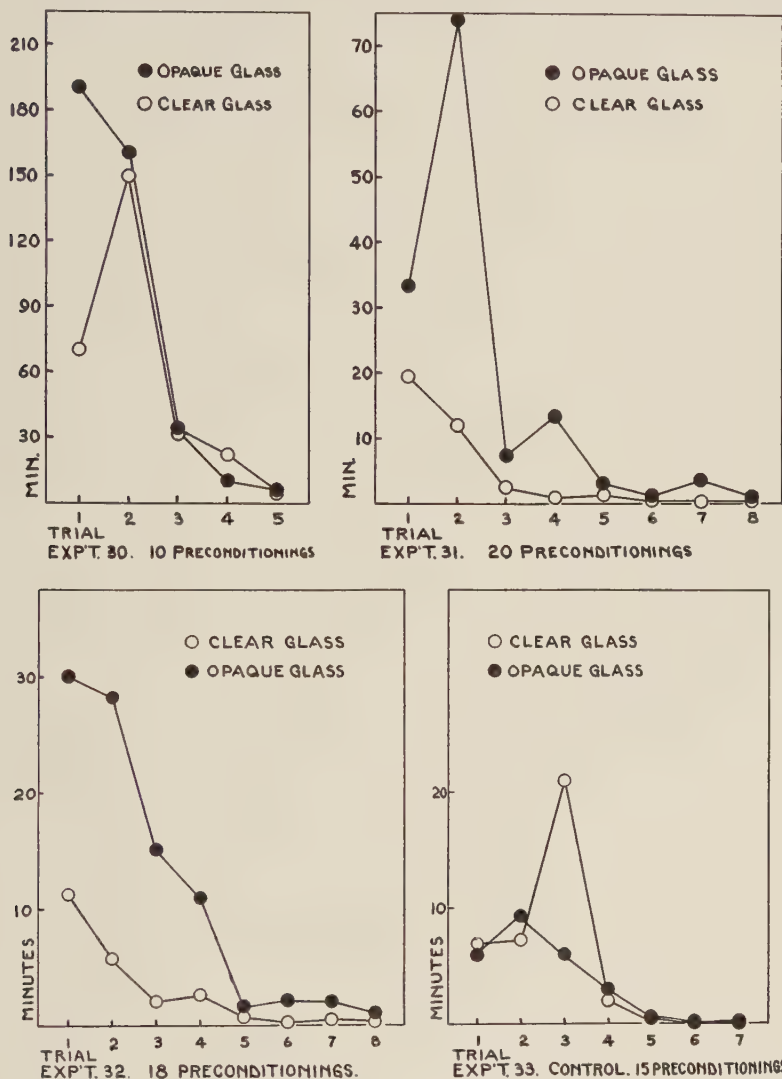


FIG. 11.—Mean reaction times of goldfishes in Experiments 30 to 33 on the effect of seeing other fishes perform a maze.

aquaria only as long as their paired clear-glass tanks. Since the trained fishes in both types of tanks responded in so nearly the same

time no great effort was necessary to insure equal lengths of presentation time. An hour after the trained fishes had been removed and the untrained fishes shifted into the larger chambers, the first trial was given to the latter. Trials were given once on each of the seven following days. The results (Fig. 11) show a clear distinction between the two types of groups: the fishes from the clear-glass tanks definitely reacted more quickly than their opaque-glass fellows.

Experiment 32.—This was a duplicate of the preceding experiment with one modification; the three untrained fishes in each tank were given 18 pre-conditionings before being shifted. The results (Fig. 11) strikingly corroborate those of Experiment 31.

Experiment 33.—To check a possible conditioning influence of the type of tank itself in the preceding experiments, a control experiment was run with new untrained fishes as follows: three goldfishes were placed in the small chamber of each tank. There were no trained leaders in the larger chambers. However, trials were run just as if there were. The cardboard front was removed from each tank in turn, its gate opened, and the feeding needle with a bit of freshly cut worm dipped in the water three times as if to feed three successively performing imaginary fishes. Then after a lapse of time equal to that of the usual trial, about 30 seconds, the tank was closed. This routine was repeated 15 times in four days; then the untrained fishes were shifted to the large chamber as before and given feeding trials just as in the previous experiments. Probably because of the hot weather, four of the twenty-four fishes died during trials. The records for tank 3 (clear glass) were deleted because of deaths and erratic behavior. Were the data for this tank included in the general summary they would not change the significance of the results. The results (Fig. 11) show clearly that the difference in behavior between the two types of groups of fishes in the preceding experiments cannot be directly attributed to the nature of the types of mazes used.

SOURCES OF DIFFICULTY AND ERROR

Many disturbing and complicating factors entered into the above experiments. For one thing, excepting *Fundulus*, fishes were selected only for health and size. Sex could not be told by external examina-

tion of such small fishes. The fishes did show signs of sex behavior such as persistent chasing of each other. Age, although not controlled, was largely eliminated as a variable through selection of size. Conditioning previous to purchase, probably unimportant, could not be controlled as the fishes were procured from a wholesale dealer.

Numerous disturbing stimuli were common. Rumbling trucks on a nearby street, slamming doors, passing people, all caused fright reactions in the fishes at times. Temperature and light were but roughly controlled. Extremely hot weather was usually accompanied with high mortality; epidemics of fluke parasites, *Gyrodactylus*, and dropsy killed others. Inherent variations were undoubtedly present in their behavior; the refractory fishes may have represented an extreme variation.

An obvious difficulty arose from the habit common among goldfishes of spitting out food and seizing it again. Sometimes after a given fish had performed and was fed, it would swim back into the original chamber from which it had come and then spit out the worm. Now and then another fish that had not yet performed would seize the food and eat it. Both fishes would be disturbed in their behavior by the experience. As another source of error the fishes showed evidence of becoming conditioned against a closed gate so that when it was opened for trials they would stick their noses half an inch through the opening and come no farther; sometimes they remained in such a position for hours.

One factor that introduced a differential stimulus resulted from multiple feedings in group tanks. The first fish to perform was always fed immediately, and quite often, if not usually, the fishes that had not yet performed saw this fish get fed. Naturally this stimulated them. That it resulted in speeding up the reaction time of the groups is an unwarranted conclusion. Observations showed that this added stimulus more commonly than not blocked the usual and more intelligent response by stimulating the fishes to a blind effort to penetrate the screen. Another variable resulted from the size of the screen opening in relation to the size of the fishes: it was such that ordinarily the fishes in groups could not come through simultaneously. This fact adds further significance to the results showing quicker

response in the groups because the restriction offered groups, but not to isolated fishes, tended to inhibit their reaction.

A somewhat subtle variable entered with the conditioning of the experimenter. In general it seems to him likely that the greater this conditioning, the more reliable the results obtained.

Another greatly disturbing factor resided in the unnaturalness of the conditions under which the fishes lived. The tanks were necessarily artificial, cramped, and angular quarters.

DISCUSSION AND CONCLUSIONS

In spite of difficulties and unknowns the experiments were performed with large enough numbers and repeated often enough that one can feel reasonably safe in drawing certain conclusions.

Groups of goldfishes in a simple maze become conditioned to a simple motor response pattern more quickly than do comparable isolated fishes. Contrary results with mudminnows on a different problem caution against generalizing.

Although group cohesion is seen to be a factor in the quicker learning of the group it is difficult to see in what way it tends to shorten reaction time. It is true that fishes reacting rapidly if isolated did no more than reduce the arithmetical mean time of reaction for all isolated fishes, whereas, if grouped, they not only had this statistical effect but exerted a physiological influence on their fellows as well. On the other hand, if this factor acts merely as a matter of group cohesion, the groups would tend to hold back the pioneers whom they later would follow. This, in fact, is what happened. Detailed data for Experiments 2 to 5 show that for the first two days the fish which gave the most rapid reaction in every experiment was found among the isolated fishes and not in the groups. Likewise, the very slowest fish to respond was found among the isolated fishes. This shows a greater variation in reaction time among the isolated fishes. Very commonly all four or eight fishes in a group will have reaction times (on a given day) not differing more than two or three seconds; very rarely did such concerted behavior appear among comparable isolated fishes. Cohesion, then, explains the more or less united response of a group but it does not explain the shorter mean reaction time of the groups.

Probably the accelerated condition of the group depends on cohesion plus two other important group effects. Although it was not possible to make quantitative measurements, observations showed clearly that inter-stimulation between members of group kept the group active at times when many of the isolated fishes in the same experiment were inactive. The greater the activity of a given fish the greater its chances of finding the gate of a maze, particularly in the earlier trials. The other group effect that probably stimulated quicker reaction time was, paradoxically, a quieting effect. Fright reactions were more common among isolated fishes; the normal relatively quiet exploratory movements were more common among grouped fishes. Once a fish in a group finds its way through a gate, group cohesion tends to pull the other after it. And, of course, tends to pull the pioneer back to the group. Having fed, however, the pioneer is less active than it was immediately before performing the maze, so the chances favor its staying put and the group coming through to it.

It is impossible to say to what extent the dropping of the learning curves actually represents learning and to what extent it represents either increased activity due to anticipation of reward or to a gradual release from inhibitions set up by the experimental conditions. That this latter is an important factor seems to be revealed by the shorter reaction time of the untrained fishes of the "imitation" Experiments 31 and 32 following twenty pre-conditionings as compared with the untrained fishes of Experiment 30 after having had only ten pre-conditionings. The greater the number of pre-conditionings the greater the freedom of the fishes from inhibitions.

The leadership experiments showed conclusively that a trained fish influences the behavior of untrained fishes. It remains to be proven that this is more than a group-cohesion phenomenon; the lure-fish experiments provide mild indications that it is.

The split-group experiments were inconclusive in that the succeeding experiments failed to give consistent results. What little evidence there was agrees with the group-learning experiments in revealing a tendency toward cohesion which would be an advantage in conditioning behavior.

The fact that members of a group eat more food in a given time than do comparable isolated fishes seems to imply some competitive

factor. Observations such as those mentioned in the introduction concerning the feeding of baby chicks and angel fishes seem to bear out this inference. The immediate explanation that occurs is that the fishes in groups stimulate each other to greater activity and hence need more food for energy production. Quite commonly isolated fishes were quiescent during the feeding period while the fishes in the groups were actively swimming about. Work by Schuett (1933), verified by Bowen (1933), on the respiration of groups of goldfishes versus isolated fishes in oil-sealed Erlenmeyer flasks showed that the fishes in groups of four used only about one-half as much oxygen per fish as did the isolated fishes under the same conditions; the same relations held for fishes contained in flasks of slowly flowing water. There still remains the possibility that the fishes in the open crystallizing dishes of the feeding experiments respired differently from the fishes in the flasks. The rapidly increasing food consumption of all the fishes in the feeding experiments can be only partially accounted for by the slight increase in the size of the fishes. It probably indicates a gradual release from inhibitions set up by the experiment; the sudden drop in consumption upon any unusual disturbance such as a shift in grouping (see Fig. 8, thirteenth trial) bears this out. Further, the fishes possibly learn to eat more rapidly as they learn that the period of feeding is restricted.

Whether fishes imitate each other seems largely to be a matter of definition of the word. Fishes probably do imitate on a low or simple instinctive level. The differential food consumption just discussed may quite well be explained on a basis of instinctive imitation rather than competition. Seeing one fish eat may set off the feeding mechanism in another fish that would otherwise not have eaten just then. The results of Experiments 29 to 33 provide no grounds for ascribing inferential imitation to the fishes involved. The results can be explained on a simpler basis. The untrained fishes that could see through the clear-glass partitions and watch their fellows react to the stimulus probably became conditioned in two ways that the untrained fishes in the opaque-glass tanks did not. First, they became "reassured" by the reaction of the trained fishes that the stimulus was not followed by harmful results. This provided a quieting effect. Secondly, they learned, through visual cohesion with the

trained fishes, to move forward with them when the stimulus was presented. In Experiments 31 and 32 the untrained fishes were at times seen even to precede the trained fishes in moving toward the stimulus in their respective chambers. Very probably there was some transfer of both types of conditioning when the untrained fishes were shifted to the larger chambers. The fishes in the opaque-glass tanks had no opportunity to acquire either of these types of conditioning. They commonly moved to the rear of their chambers and remained there during each of the pre-conditioning trials.

The results of these experiments relate to schooling in several significant items. An attempt was made to determine whether goldfishes school by turning 26 of them loose in a pond about 50 feet in diameter. They scattered immediately and were never seen after that although efforts were made to find them at intervals during the two months that followed. In small concrete outdoor pools nine feet square goldfishes were observed to school at times and to be scattered at other times. In aquaria they tended to school when disturbed. If it should be generally true that fishes learn more readily in groups than when isolated, great survival value would attach to schooling behavior, especially among young fishes. Parr (1927) discovered that an isolated three-inch chub mackerel would join a school of seven-inch mackerels quite readily, but that an isolated seven-inch fish would not join a school of smaller fishes. One can easily read an educational significance into such behavior.

The survival value of imitating the behavior of the group, particularly the imitation of adult members by the young, depends on the inherent survival value of the behavior patterns of the adult group. In human society reforms and innovations are often more desirable than blind imitation. However, these desirable changes rarely have to do with biological necessities—with such things as eating, mating, sleeping. They are more concerned with religion, art, politics, economics: biological non-essentials. In fishes the behavior patterns are rigorously limited to biological necessities. Very probably the behavior repertory of a given species of fish has been refined through long ages of evolution into an exceedingly efficient mechanism for fitting that species into its environmental niche. Therefore, the sooner a fish acquires the non-instinctive behavior of the

group, probably the better are its chances for survival. To illustrate: disregarding the possibility that bottom-scavenging is *purely* instinctive, a young goldfish schooling with and to some extent imitating the feeding habits of its older fellows will obtain a survival advantage over a fish reared alone. It will learn a type of effective feeding for which its carp-mouth is eminently adapted before it could have evolved a successful individual technique. Be it ever so slight, the advantage would provide survival value. While the illustration is imaginary, the principle may be quite real. Schooling undoubtedly affords enhanced opportunity for such learning by precept. The group-feeding experiments disclose a mechanism that seems to have a quite obvious survival value. The fact that a fish will eat more food and eat it more quickly when in a group than when isolated probably in the long run aids survival. With the supply of food limited as it nearly always is, the species without this mechanism is the one that will first starve.

The food-drive experiments open up further interesting problems. One can easily see why fishes react more slowly when satiated with food, but it is less easy to understand why they should speed up their reactions so greatly on successive trials without feedings. Stimulus-summation offers a tentative explanation. More than relative hunger is involved because the fishes that have been deprived of food for three days do not react as quickly as they do on the third successive non-feeding trial after only the usual one-day deprivation.

The experiments on retention are inconclusive in regard to differential effects of grouping. They need to be repeated under better conditions for survival and non-disturbance. It seems quite likely that there is within the group a mechanism that enhances retention. One fish, for example, that remembers a maze after a lapse of a month may conceivably stimulate others to perform it successfully. On the other hand, *a priori*, an opposite effect seems just as possible. Hunter (1929) summarizing experimental work in human retention shows that retention depends in part upon the type of activity undertaken during the retention period. Subjects merely resting after learning a set of nonsense syllables remembered them better than did subjects studying something else between learning and recall. The nervous stimulation of group activity in fishes may conceiv-

ably prove to be a retention-inhibiting factor analogous to such interspersed mental activity in man. Here is an interesting field for further exploration.

That the group should influence the behavior of its members is to be expected, particularly so in the light of numerous experiments in the field of animal aggregations. Uvarov, whose work has been verified by Faure (1932), finds that crowding affects the structure and color phase of migratory locusts; Pearl and Surface find that egg-production in hens increases inversely with the size of the flock, and attribute this effect to a psychological factor; Reinhard and others have shown that crowding in aphids indirectly influences wing-production; Banta and Brown and Stuart show that sex in *Cladocera* is likewise influenced by crowding, the more crowded females producing the higher percentage of males. If morphology and physiology can be influenced to such an extent by the crowd, surely there are good reasons for expecting a crowd-influence on the behavior of animals, which after all is a species of physiology. For an exhaustive summary of the effects of aggregation on morphology and physiology, and for references to the instances just mentioned, see Allee's (1931) *Animal Aggregations*.

There are several logical channels into which this present inquiry might lead. The problem of the influence of numbers on appetite and food consumption has been mentioned. Another broader problem might deal with the nature and significance of the group influence on an unconscious level. A study of the effects of group size should be applied to animals as Hudelson and others have applied it in the field of human education. A more complete understanding of the function of childhood might contribute greatly to solving problems of group organization and education. Groos (1911) points out that play in the young of animals affords practice and exercise which provide requisite skill and strength for later independent life. The important facts seem to be that play is usually restricted to young animals and is *social*. A phylogeny of play—the evolutionary history of the relationship of youthful activity to adult group behavior—needs to be investigated.

The present investigation has shown that the group is a force in shaping the behavior of its members even when the group is com-

posed of animals low in the vertebrate scale. It has demonstrated that ends providing survival value may be gained through a group influence.

SUMMARY

1. Under certain experimental conditions mudminnows in groups exhibit an antagonistic behavior that inhibits learning.
2. Goldfishes become conditioned to run a simple maze more rapidly when grouped than when isolated.
3. A trained goldfish in a maze with an untrained fish will speed up the conditioning of the latter.
4. The group seems to stimulate learning behavior in three related ways: through group cohesion visually integrated; through an inter-"reassurance" that tends to remove environmentally induced inhibitions; through an interaction between members of the group that stimulates exploratory activity.
5. A goldfish learns to run a simple maze more rapidly after having seen other goldfishes run it.
6. There are indications that groups of goldfishes retain conditioned motor responses better than do isolated fishes.
7. A limited number of successive no-reward trials greatly stimulates conditioned responses in both grouped and isolated fishes.
8. Successive reward trials slow down conditioned responses in goldfishes, grouped or isolated.
9. Goldfishes, paradise fishes, zebra fishes and shiners eat more food per fish in groups than when isolated.

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